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Evaluation of Lettuce Genotypes for Salinity Tolerance

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Abstract. **Lettuce is one of the most commonly used salad vegetables and considered to be a relatively salt-sensitive crop. Salinity is a major constraint to crop production in all important lettuce growing regions of the United States, and the water quality problem is exacerbated by climate change. To identify salt-tolerant lettuce genotypes, 178 cultivars and germplasm accessions (56 butterhead, 39 crisphead, 35 romaine, 33 leaf, and 15 wild types) were selected from a preliminary screening of more than 3800 genotypes, and tested for salinity tolerance in sand cultures under greenhouse conditions. Plants were grown in Hoagland nutrient solution, either with or without 30/15 mM $NaCl/CaCl_2$, and leaf fresh and dry mass (FM and DM), chlorophyll index, and maximal photochemical efficiency (F_v/F_m) were measured 4 weeks after plants were transplanted. Generally, salinity decreased lettuce shoot FM and DM, increased DM/FM ratio and chlorophyll index, and had no effect on F_v/F_m. Some lettuce varieties showed salt tolerance (less than 15% reduction in FM), such as PI 342515, PI 358020c, 'Morgana', 'Amerika' (butterhead), 'Laura' (crisphead), PI 289023, PI 273577, PI 278066, PI 177425 (romaine), PI 171676a, PI 177423, PI 342477, and PI 358018b (leaf). The results indicate that lettuce genotypes differ greatly in their salt sensitivity, which could be useful for growers to choose cultivars and for breeders to improve lettuce adaptation to salinity stress.**

Salinity of soil and irrigation water is a growing problem for agricultural production in the world. It is estimated that salt-affected soils impact on nearly 10% of the land surface and 50% of irrigated land in the world (Ruan et al., 2010). Global warming promotes water transpiration from plants and evaporation from soil, thereby increasing salt accumulation in soil. Salinity effects on plants include cellular water deficit, ion toxicity, nutrient deficiencies, and oxidative stress, which can lead to growth inhibition, molecular damage, and even plant death (Orcutt and Nilsen, 2000). The global annual losses in agricultural production from salt-affected land are in excess of U.S. $12 billion and rising (Flowers et al., 2010; Qadir et al., 2008).

Lettuce (*Lactuca sativa* L.) is one of the most important salad vegetables in the United States, and contains important phytochemicals, including vitamins, carotenoids, and other antioxidants (Humphries and Khachik, 2003; Nicolle et al., 2004). It is considered to be a relatively salt-sensitive vegetable (Shannon and Grieve, 1999). Salt stress reduced lettuce germination, leaf water content, photosynthesis rate, chlorophyll content, root and shoot growth, and increased sodium and chloride ion concentration and lipid peroxidation (Barassi et al., 2006; Eraslan et al., 2007; Kaya et al., 2002; Mohammadi and Khoshgoftarmanesh, 2014; Mota-Cadenas et al., 2010; Pérez-López et al., 2013; Shannon et al., 1983).

One approach to enhance lettuce production in saline soils and water is to develop salt-tolerant cultivars, which may be achieved by exploiting intraspecific variability (Dewey, 1962; Wei et al., 2014). Considerable variability in salt tolerance was found among 85 lettuce cultivars and breeding lines in one experiment (Shannon et al., 1983), although there was little variability in salt tolerance among 6 lettuce cultivars in another (Ayers et al., 1951). Furthermore, Shannon and McCreight (1984) screened 115 PIs of lettuce for salt tolerance and found that PIs had a wider range of salt tolerance and a higher mean average salt tolerance than standard cultivars. Several wild relatives of cultivated lettuce, *Lactuca serriola*, *Lactuca Vignata*, and *Lactuca saligna*, had an even higher range of tolerance than the introductions (Shannon and Grieve, 1999). However, they noted that their tolerance ratings were measured in terms of absolute growth under high salinity, and therefore did not account for natural difference in total growth potential that may exist between cultivars or PIs (Shannon and McCreight, 1984). Moreover, most lettuce cultivars and PIs have not been screened for salt tolerance yet. The objectives of this study were to screen lettuce germplasm and cultivars for their salinity tolerance in comparison with plants grown under control conditions, and identify traits related to salt tolerance.

Materials and Methods

Plant materials. Based on preliminary tests, 178 lettuce cultivars and germplasm accessions (56 butterhead, 39 crisphead, 35 romaine, 33 loose leaf, and 15 wild genotypes) were selected from more than 3800 cultivars and germplasm accessions in the lettuce collections at the U.S. Department of Agriculture in Salinas (36°40′40′′N 121°39′20′′W), CA, and screened for their tolerance to salinity.

Plant growth and measurements. Two trials, each with three replications, were conducted from 18 Nov. 2014 to 22 Dec. 2014 and 18 Dec. 2014 to Jan. 21, 2015, in a greenhouse located in Salinas, CA. The greenhouse was supplemented with light of a 12-h photoperiod using Sun System 3 (Sunlight Supply Inc., Vancouver, WA).

Seeds of each genotype were sown in rock wool cells (Grodan Group, Roermond, Netherlands). One week after seeding, uniform seedlings were transplanted into plastic pots (1 L) filled with sand. Plants were thinned to one plant per pot and watered every day with Hoagland nutrient solution [electrical conductivity (EC): 2.5 ds/m] (Hoagland and Arnon, 1950). Salinity stress was induced by adding $NaCl/CaCl_2$ solution of 10/5 and then 20/10 mM in the nutrition solution for 2-d intervals at each concentration, and then by adding 30/15 mM $NaCl/CaCl_2$ (EC: 8.4 ds/m). Exposure of plants to increasing salt concentration allowed gradual acclimation of plants to salinity conditions to avoid sudden death of plants at high salt concentration. Care was taken to avoid contact of the salt solution with the leaves to minimize potential salt-induced leaf burning. Control plants were only watered with Hoagland solution.

Four weeks after transplanting, leaf chlorophyll index (SPAD) and maximum photochemical efficiency (F_v/F_m) were measured on the two largest leaves from each plant, then plants were harvested to measure shoot FM and DM. Shoot DM was measured after drying at 60 °C for 3 d. Leaf chlorophyll index was measured with a SPAD-502 m (Konica Minolta Sensing Inc., Tokyo, Japan). Leaf F_v/F_m was measured with a MINI-PAM-II fluorometer (Heinz Walz, Effeltrich, Germany) after leaves were adapted in darkness for 30 min.

Statistical analysis. A complete randomized design was used in this experiment. Each biological replicate contained one pot. Treatment means were evaluated for significant differences with Student's *t* test at the 0.05 level of probability using the JMP program (SAS Institute Inc., Cary, NC). The interaction between the two trials was not significant so data were pooled together with six replications.

Results and Discussion

Nearly identical effects of salinity on growth at 30 and 60 d was reported by Shannon et al., (1983), indicating that early screening for salt

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tolerance in lettuce was reliable for measuring salt tolerance at later growth stage. Therefore, in this study shoot FM, DM, DM/FM ratio, and leaf SPAD and F_v/F_m were measured 4 weeks after salt stress. Regardless of lettuce types, salinity generally decreased shoot FM and DM, increased DM/FM ratio and SPAD values (Tables 1–5), but had no effects on F_v/F_m (data not shown). Shoot FM was reduced by salinity in many more genotypes than shoot DM, indicating FM was more sensitive to salinity stress than shoot DM. This may result from increased ratio of DM/FM. Also previous studies indicated lettuce leaf water content decreased in response to salinity (Pérez-López et al., 2013; Shannon et al., 1983). Lower leaf water content results in stomatal closure and loss of cell turgor pressure and expansion, leading to reduced photosynthetic rate and leaf area. Reduced photochemical efficiency under salt stress was reported in red leaf but not in green-leaf lettuce (Pérez-López et al., 2013). However, in the present study, F_v/F_m was not altered in all genotypes. The inconsistency might result from plant types, severity, and duration of salinity stress. Salinity increased SPAD values in most genotypes indicating higher chlorophyll content per leaf area. Similarly as observed in field studies, moderately salt-stressed lettuce was darker green in color (Ayers et al., 1951; Shannon, 1980). In the present study, shoot FM was not correlated with SPAD value ($R^2 = 0.22$) or DM/FM ratio ($R^2 = 0.32$).

Butterhead lettuce. Under control condition, the cultivars with high shoot FM were Plenos (4.9 g), Dark Green Boston (4.4 g), Butter Crunch (4.3 g), Bibb (4.3 g), Continuity

Table 1. Effects of salinity on fresh and dry mass and chlorophyll index in butterhead lettuce.

	Fresh mass (FM, g)			Dry mass (DM, mg)		DM/FM		SPAD	
Genotypes	Control	Salt	%	Control	Salt	Control	Salt	Control	Salt
PI 342515	2.5 ± 0.37[z]	2.2 ± 0.39	–12	147 ± 21	134 ± 23	0.058 ± 0.0032	0.062 ± 0.0026	21.8 ± 0.70	24.0 ± 0.74
PI 358020c	3.1 ± 0.32	2.7 ± 0.35	–12	177 ± 17	207 ± 26	0.060 ± 0.0019 b	0.076 ± 0.0052 a	16.6 ± 0.90 b	20.5 ± 1.87 a
Morgana	2.7 ± 0.43	2.4 ± 0.42	–13	167 ± 30	160 ± 25	0.065 ± 0.0014	0.069 ± 0.0035	28.0 ± 0.74	30.0 ± 1.67
Amerika	2.0 ± 0.21	1.8 ± 0.19	–14	115 ± 11	113 ± 12	0.056 ± 0.0008 b	0.065 ± 0.0001 a	22.0 ± 0.84	24.7 ± 0.93
Nadine	2.0 ± 0.29	1.6 ± 0.23	–23	130 ± 18	113 ± 17	0.058 ± 0.0016 b	0.073 ± 0.0008 a	21.4 ± 1.04	23.6 ± 1.30
PI 503605a	2.3 ± 0.14	1.8 ± 0.25	–24	142 ± 9	122 ± 17	0.064 ± 0.0019	0.068 ± 0.0017	18.2 ± 3.33	20.6 ± 1.89
Borough Wonder	2.0 ± 0.17	1.5 ± 0.31	–25	134 ± 13	102 ± 21	0.066 ± 0.0033	0.069 ± 0.0019	16.9 ± 0.48	18.7 ± 0.81
Campan	2.7 ± 0.28 a[y]	2.0 ± 0.17 b	–25	160 ± 18	132 ± 12	0.057 ± 0.0014 b	0.065 ± 0.0014 a	23.2 ± 1.02	24.5 ± 0.67
Evry	2.3 ± 0.34	1.8 ± 0.15	–26	134 ± 18	123 ± 18	0.060 ± 0.0027	0.069 ± 0.0050	19.7 ± 0.46 b	22.6 ± 0.80 a
Canada Boston	1.9 ± 0.11 a	1.4 ± 0.10 b	–26	108 ± 5	92 ± 6	0.055 ± 0.0016 b	0.064 ± 0.0011 a	20.9 ± 1.34	24.7 ± 1.19
Sitonia	2.0 ± 0.15 a	1.5 ± 0.14 b	–27	114 ± 10	98 ± 9	0.057 ± 0.0014 b	0.066 ± 0.0024 a	23.4 ± 0.95	26.9 ± 1.29
Atlas Non-Bolting	3.1 ± 0.20 a	2.3 ± 0.25 b	–27	187 ± 9	162 ± 17	0.060 ± 0.0013 b	0.071 ± 0.0010 a	29.9 ± 1.14 b	35.1 ± 0.85 a
PI 342448	1.4 ± 0.18	1.0 ± 0.17	–29	88 ± 16	75 ± 14	0.068 ± 0.0041	0.080 ± 0.0071	14.6 ± 0.56 b	17.2 ± 0.83 a
Brauner Trotzkopf	2.3 ± 0.17 a	1.6 ± 0.16 b	–30	158 ± 28	113 ± 12	0.068 ± 0.0021	0.070 ± 0.0006	17.5 ± 0.43 b	19.9 ± 0.71 a
PI 503632	2.5 ± 0.28	1.7 ± 0.20	–30	147 ± 19	127 ± 14	0.066 ± 0.0020 b	0.074 ± 0.0026 a	18.3 ± 0.44 b	20.8 ± 0.67 a
PI 358019a	3.4 ± 0.37 a	2.3 ± 0.46 b	–30	207 ± 23	181 ± 34	0.061 ± 0.0017 b	0.078 ± 0.0022 a	15.8 ± 0.51 b	19.9 ± 1.61 a
Salad Bibb	1.6 ± 0.03 a	1.1 ± 0.10 b	–31	120 ± 24	93 ± 25	0.075 ± 0.0009	0.084 ± 0.0056	34.1 ± 1.23	34.4 ± 1.38
North Pole	2.9 ± 0.28 a	2.0 ± 0.16 b	–32	180 ± 18	138 ± 12	0.060 ± 0.0014 b	0.071 ± 0.0022 a	18.3 ± 1.20	19.4 ± 0.60
Margarita	2.8 ± 0.16 a	1.8 ± 0.18 b	–33	156 ± 18	125 ± 10	0.066 ± 0.0008	0.070 ± 0.0020	29.2 ± 1.54	33.2 ± 1.50
Futura	3.3 ± 0.17 a	2.2 ± 0.30 b	–33	198 ± 14	154 ± 23	0.060 ± 0.0020 b	0.070 ± 0.0019 a	17.3 ± 0.68	18.9 ± 0.44
Valore	2.9 ± 0.26 a	1.9 ± 0.15 b	–34	171 ± 23	126 ± 10	0.063 ± 0.0022	0.066 ± 0.0014	15.2 ± 0.86 b	19.1 ± 0.94 a
Sandrina	3.5 ± 0.15 a	2.3 ± 0.18 b	–34	192 ± 6 a	152 ± 11 b	0.056 ± 0.0010 b	0.067 ± 0.0025 a	15.7 ± 0.58 b	18.9 ± 0.59 a
Massilia	3.0 ± 0.29 a	2.0 ± 0.31 b	–34	175 ± 19	134 ± 21	0.062 ± 0.0015	0.067 ± 0.0019	25.7 ± 0.78	28.6 ± 1.12
Bonanza	2.5 ± 0.33 a	1.7 ± 0.20 b	–34	169 ± 21	117 ± 14	0.064 ± 0.0012 b	0.070 ± 0.0012 a	32.8 ± 0.41 b	36.5 ± 0.95 a
Sissy	2.7 ± 0.11 a	1.8 ± 0.33 b	–35	159 ± 10	133 ± 27	0.060 ± 0.0016 b	0.074 ± 0.0018 a	24.3 ± 0.54 b	31.3 ± 1.32 a
May Queen	3.0 ± 0.31 a	1.9 ± 0.33 b	–35	180 ± 20	138 ± 28	0.060 ± 0.0017 b	0.073 ± 0.0047 a	15.7 ± 0.33 b	19.5 ± 1.29 a
Nancy	1.9 ± 0.17 a	1.2 ± 0.13 b	–35	118 ± 9	96 ± 12	0.058 ± 0.0008 b	0.077 ± 0.0034 a	20.8 ± 1.28	23.3 ± 1.37
Plenos	4.9 ± 0.58 a	3.0 ± 0.29 b	–38	251 ± 35	197 ± 20	0.055 ± 0.0018 b	0.066 ± 0.0011 a	18.1 ± 0.59 b	24.8 ± 2.12 a
Raphaela	3.0 ± 0.15 a	1.9 ± 0.25 b	–39	163 ± 9 a	120 ± 15 b	0.056 ± 0.0002 b	0.065 ± 0.0023 a	29.0 ± 0.69	30.7 ± 2.39
Vitius	3.5 ± 0.43 a	2.1 ± 0.22 b	–39	211 ± 27 a	141 ± 15 b	0.064 ± 0.0020	0.067 ± 0.001	18.2 ± 0.71	19.9 ± 1.35
Continuity	4.2 ± 0.27 a	2.5 ± 0.16 b	–40	233 ± 18 a	172 ± 10 b	0.058 ± 0.0011 b	0.068 ± 0.0015 a	25.0 ± 0.77 b	31.0 ± 1.87 a
Devonshire Cream	2.4 ± 0.20 a	1.4 ± 0.19 b	–40	152 ± 14 a	104 ± 14 b	0.067 ± 0.0015 b	0.074 ± 0.0007 a	15.8 ± 0.28 a	18.6 ± 0.71 b
Ewex	3.3 ± 0.21 a	2.0 ± 0.19 b	–41	210 ± 26 a	156 ± 12 b	0.067 ± 0.0018 b	0.078 ± 0.0011 a	17.8 ± 0.81	19.5 ± 0.80
PI 503606	3.3 ± 0.23 a	1.9 ± 0.16 b	–41	187 ± 14 a	128 ± 10 b	0.060 ± 0.0010	0.066 ± 0.0025	15.8 ± 1.90	16.0 ± 0.45
PI 342516	2.2 ± 0.33 a	1.4 ± 0.25 b	–41	155 ± 14 a	93 ± 16 b	0.064 ± 0.0035	0.069 ± 0.0012	19.5 ± 0.86	19.9 ± 1.14
PI 289029	3.9 ± 0.41 a	2.3 ± 0.17 b	–42	221 ± 25 a	157 ± 12 b	0.058 ± 0.0027 b	0.068 ± 0.0010 a	15.3 ± 0.79 b	19.7 ± 0.39 a
Burpee's Bibb	3.9 ± 0.45 a	2.2 ± 0.29 b	–42	215 ± 27	147 ± 18	0.058 ± 0.0015 b	0.066 ± 0.0011 a	34.8 ± 0.91 b	38.6 ± 0.87 a
PI 289036c	2.8 ± 0.19 a	1.6 ± 0.28 b	–43	181 ± 11 a	119 ± 21 b	0.066 ± 0.0010 b	0.075 ± 0.0020 a	18.8 ± 1.05	21.6 ± 0.72
Bourguignonne	3.9 ± 0.40 a	2.2 ± 0.09 b	–43	240 ± 25 a	149 ± 7 b	0.059 ± 0.0012 b	0.067 ± 0.0018 a	13.8 ± 0.78 b	17.2 ± 0.99 a
PI 289025	2.8 ± 0.16 a	1.6 ± 0.19 b	–43	191 ± 9 a	119 ± 14 b	0.067 ± 0.0020	0.074 ± 0.0021	15.8 ± 0.32 a	17.4 ± 0.40 b
Dark Green Boston	4.4 ± 0.49 a	2.5 ± 0.37 b	–44	257 ± 27 a	165 ± 17 b	0.067 ± 0.0002 b	0.072 ± 0.0021 a	31.8 ± 5.32	26.9 ± 1.88
PI 289023a	3.2 ± 0.24 a	1.8 ± 0.16 b	–44	189 ± 14 a	129 ± 12 b	0.059 ± 0.0013 b	0.074 ± 0.0035 a	13.1 ± 0.95 b	18.2 ± 1.70 a
Escort	3.2 ± 0.15 a	1.7 ± 0.30 b	–45	208 ± 13 a	135 ± 24 b	0.067 ± 0.0023 b	0.078 ± 0.0005 a	24.7 ± 1.15 b	28.2 ± 0.79 a
Mignonette Dark Green	3.6 ± 0.43 a	2.0 ± 0.21 b	–45	201 ± 22 a	141 ± 16 b	0.059 ± 0.0015 b	0.071 ± 0.0021 a	25.3 ± 1.06	27.7 ± 1.37
PI 373915	3.2 ± 0.26 a	1.7 ± 0.15 b	–46	178 ± 18 a	119 ± 10 b	0.059 ± 0.0016 b	0.069 ± 0.0013 a	15.0 ± 0.80 b	18.4 ± 0.99 a
Butter King	3.1 ± 0.21 a	1.6 ± 0.20 b	–48	180 ± 12 a	104 ± 12 b	0.059 ± 0.0017	0.066 ± 0.0033	21.4 ± 0.81 b	25.1 ± 1.21 a
Red Boston	3.6 ± 0.31 a	1.9 ± 0.32 b	–48	225 ± 23 a	145 ± 17 b	0.065 ± 0.0036	0.076 ± 0.0042	16.1 ± 0.46	17.9 ± 0.80
Burpeeana	4.1 ± 0.52 a	2.1 ± 0.25 b	–48	219 ± 22 a	145 ± 21 b	0.056 ± 0.0011 b	0.068 ± 0.0009 a	34.1 ± 1.11 b	39.9 ± 1.53 a
Butter Crunch	4.3 ± 0.20 a	2.2 ± 0.05 b	–49	274 ± 13 a	173 ± 4 b	0.063 ± 0.0008 b	0.078 ± 0.0012 a	32.1 ± 1.30	32.0 ± 1.81
PI 342453	2.8 ± 0.20 a	1.4 ± 0.13 b	–49	168 ± 12 a	102 ± 8 b	0.063 ± 0.0020 b	0.072 ± 0.0015 a	18.1 ± 1.25	19.7 ± 1.07
Tania (550)	3.1 ± 0.22 a	1.6 ± 0.19 b	–49	180 ± 13 a	117 ± 16 b	0.061 ± 0.0003 b	0.073 ± 0.0032 a	24.8 ± 0.78	22.0 ± 2.29
Bibb	4.3 ± 0.47 a	2.1 ± 0.40 b	–51	255 ± 28 a	139 ± 26 b	0.060 ± 0.0025	0.066 ± 0.0010	40.0 ± 3.67	39.6 ± 1.56
Mayfair	2.5 ± 0.08 a	1.2 ± 0.28 b	–52	148 ± 7 a	83 ± 17 b	0.060 ± 0.0017 b	0.072 ± 0.0040 a	20.2 ± 3.58	18.1 ± 0.67
PI 358015b	3.1 ± 0.39 a	1.5 ± 0.15 b	–54	179 ± 23 a	104 ± 10 b	0.062 ± 0.0013 b	0.072 ± 0.0009 a	18.7 ± 0.84 b	23.7 ± 1.50 a
PI 373914	1.6 ± 0.17 a	0.7 ± 0.07 b	–54	115 ± 19 a	59 ± 7 b	0.072 ± 0.0056	0.079 ± 0.0035	15.1 ± 0.68 b	17.7 ± 0.77 a
PI 289062	3.4 ± 0.37 a	1.4 ± 0.14 b	–58	189 ± 22 a	106 ± 9 b	0.058 ± 0.0025 b	0.075 ± 0.0017 a	15.4 ± 0.48 b	19.3 ± 0.59 a

[z]Means of two trial followed with standard error (n = 6).

[y]Means followed by different letters within each genotype for each parameter indicate significant difference at $P \leq 0.05$ according to Student's *t* test.

(4.2 g), and Burpeeana (4.1 g) (Table 1). Wide differences exist among 54 butterhead lettuce cultivars and germplasm accessions in their absolute growth under salinity stress. Shoot FM ranged from 0.7 to 3.0 g and DM from 59 to 207 mg (Table 1). The nine genotypes with highest FM were 'Plenos' (3.0 g), PI 358020c (2.7 g), 'Continuity' (2.5 g), 'Dark Green Boston' (2.5 g), 'Morgana' (2.4 g), 'Atlas Non-bolting' (2.3 g), 'Sandrina' (2.3 g), PI 358019a (2.3 g), and PI 289029 (2.3 g). Plenos, Continuity, and Dark Green Boston were cultivars with highest absolute growth under both control and salinity stress. The five most sensitive ones in absolute growth were PI 372914 (0.7 g), PI 342448 (1.0 g), 'Salad Bibb' (1.1 g), 'Nancy' (1.2 g), and 'Mayfair' (1.2 g). In a previous study (Shannon et al., 1983), both 'Bibb' and 'Burpee's Bibb' were identified as salt sensitive since their FM were much less than the FM of Butter Crunch. However, in this study, the FM of 'Bibb' and 'Burpee's Bibb' were similar to the FM of 'Butter Crunch', which was consistent with the result of Shannon and McCreight (1984).

Tolerance ratings in terms of absolute growth do not account for natural difference in growth potential that may exist among genotypes. Compared with shoot FM without salt stress, the shoot FW of 10 genotypes ('Morgana', 'Amerika', 'Nadine', 'Borough Wonder', 'Every', PI 342515, PI 358020c, PI 503605a, PI 342448, and PI 503632) were not significantly reduced by salinity. Based on the percent reduction in FM of salt stressed plants compared with plants grown under control conditions, four genotypes (PI 342515, PI 358020c, 'Morgana', and 'Amerika') showed high tolerance with less than 20% FM reduction and nine genotypes ('Nadine', PI 503605a, 'Borough Wonder', 'Campan', 'Every', 'Canada Boston', 'Sitonia', 'Atlas Non-bolting', and PI 342448) have moderate tolerance with less than 30% reduction. The most sensitive genotypes with more than 50% reduction were PI 289062, PI 373914, PI 358015b, 'Mayfair', and 'Bibb'. 'Morgana' and were the most tolerant genotype based on either absolute or relative growth.

Crisphead lettuce. The cultivars with high growth under control conditions were Red Coach (4.8 g), Sniper (4.8 g), Tiber (4.3 g), Laupili (4.3 g), Alpine (4.2 g), and Imperial 749 (4.2 g) (Table 2). Shoot FM under salinity stress ranged from 0.8 to 2.9 g, and DM ranged from 55 to 208 mg. Based on the absolute growth under salt stress, cultivars Alpine (2.9 g), Red Coach (2.9 g), Laupili (2.8 g), Tiber (2.7 g), Bursc 17 (2.6 g), Mid Queen (2.6 g), Empire BPTS (2.5 g), Excell (2.5 g), and Sniper (2.5 g) were the most tolerant ones, while cultivars Sumi (0.8 g), Great Lakes Premier (1.2 g), E 8248 (1.4 g), and Burpee's Iceberg (1.4 g) were sensitive ones. The cultivars with the highest growth potential under both control and salinity were Red Coach, Sniper, Tiber, Laupili, and Alpine. Red coach was also identified as a tolerant cultivar based on absolute growth in a previous screening (Shannon and McCreight, 1984).

Salinity stress did not significantly reduce shoot FM of nine cultivars (Laura, Grandeverde, Casper, Batavia de Pierre Benite, Burpee's Iceberg, Batavia Flavia, Cannery Row, Bursc 17, and Salinas). In terms of relative tolerance, cultivars Laura, Grandeverde, Casper, Batavia de Pierre Benite, and Burpee's Iceberg showed high tolerance with less than 20% reduction in FW of salt stressed plants compared with control plants, and cultivars Batavia Flavia, Cannery Row, Bursc 17, Salinas, Great Lakes J strain, and Batavia Blonde a Bord Rouge showed moderate tolerance with less than 30% reduction in FW. The E 8248 and Early Bird were the most sensitive cultivars with 56% and 54%

Table 2. Effects of salinity on fresh and dry mass and chlorophyll index in crisphead lettuce.

	Fresh mass (FM, g)			Dry mass (DM, mg)		DM/FM		SPAD	
Genotypes	Control	Salt	%	Control	Salt	Control	Salt	Control	Salt
Laura	2.1 ± 0.19[z]	2.2 ± 0.25	4.5	109 ± 10	125 ± 15	0.050 ± 0.0012 b	0.057 ± 0.0010 a	14.4 ± 0.48 b	18.9 ± 1.55 a
Grandeverde	2.1 ± 0.38	1.8 ± 0.17	–15	137 ± 22	118 ± 13	0.060 ± 0.0015 b	0.066 ± 0.0017 a	30.2 ± 2.58	36.4 ± 1.97
Casper	2.5 ± 0.28	2.1 ± 0.23	–16	172 ± 21	153 ± 16	0.070 ± 0.0008	0.074 ± 0.0013	29.1 ± 0.97	32.5 ± 1.61
Batavia de Pierre Benite	2.2 ± 0.21	1.8 ± 0.12	–18	125 ± 12	116 ± 9	0.054 ± 0.0008 b	0.065 ± 0.0013 a	15.3 ± 0.89	19.0 ± 1.90
Burpee's Iceberg	1.7 ± 0.31	1.4 ± 0.22	–18	122 ± 18	98 ± 15	0.061 ± 0.0014 b	0.070 ± 0.0006 a	15.3 ± 1.67 b	19.7 ± 0.88 a
Batavia Flavia	1.8 ± 0.14	1.5 ± 0.19	–20	101 ± 6	101 ± 13	0.057 ± 0.0016 b	0.069 ± 0.0017 a	18.5 ± 2.74	18.3 ± 1.34
Cannery Row	2.1 ± 0.23	1.7 ± 0.06	–20	140 ± 16 a	118 ± 6 b	0.065 ± 0.0016	0.070 ± 0.0014	32.7 ± 1.04 b	36.7 ± 1.17 a
Bursc no. 17	3.3 ± 0.17	2.6 ± 0.23	–20	184 ± 11	173 ± 13	0.058 ± 0.0014 b	0.067 ± 0.0019 a	31.4 ± 1.41	35.5 ± 2.94
Campionas	2.8 ± 0.15 a[y]	2.1 ± 0.20 b	–23	184 ± 11	154 ± 18	0.067 ± 0.0013	0.094 ± 0.0175	33.3 ± 1.09	36.2 ± 1.34
Mid Queen	3.4 ± 0.30 a	2.6 ± 0.13 b	–24	203 ± 16	169 ± 8	0.057 ± 0.0008 b	0.065 ± 0.0016 a	32.8 ± 1.07	30.8 ± 3.81
Salinas	3.1 ± 0.41	2.3 ± 0.11	–27	186 ± 24	161 ± 11	0.062 ± 0.0006	0.065 ± 0.0009	32.5 ± 1.20	35.8 ± 1.32
Great Lakes J Strain	2.2 ± 0.25 a	1.6 ± 0.16 b	–28	125 ± 23	111 ± 24	0.059 ± 0.0015 b	0.071 ± 0.0007 a	31.1 ± 1.38	34.3 ± 1.81
Empire BPTS	3.5 ± 0.26 a	2.5 ± 0.14 b	–28	228 ± 18 a	176 ± 10 b	0.065 ± 0.0011 b	0.071 ± 0.0006 a	28.2 ± 1.05 b	33.6 ± 1.02 a
Bogota	3.4 ± 0.16 a	2.4 ± 0.32 b	–28	189 ± 8	173 ± 25	0.056 ± 0.0003 b	0.071 ± 0.0025 a	29.6 ± 0.97	30.2 ± 0.81
Batavia Blonde A Bord Rouge	3.0 ± 0.23 a	2.1 ± 0.19 b	–29	166 ± 14	152 ± 21	0.057 ± 0.0015 b	0.072 ± 0.0021 a	16.3 ± 0.87	19.0 ± 1.58
E 9278	3.0 ± 0.25 a	2.1 ± 0.28 b	–30	199 ± 20	154 ± 21	0.064 ± 0.0019 b	0.073 ± 0.0008 a	30.8 ± 0.57 b	34.4 ± 1.45 a
Kulanui	2.7 ± 0.31 a	1.9 ± 0.22 b	–31	185 ± 10 a	135 ± 16 b	0.066 ± 0.0024	0.071 ± 0.0011	32.6 ± 0.81	31.5 ± 0.98
Alpine	4.2 ± 0.48 a	2.9 ± 0.24 b	–31	239 ± 21 a	185 ± 11 b	0.057 ± 0.0017 b	0.064 ± 0.0014 a	23.0 ± 1.22 b	29.5 ± 1.20 a
Alpha II	2.4 ± 0.16 a	1.6 ± 0.24 b	–31	152 ± 10	113 ± 17	0.062 ± 0.0024	0.068 ± 0.0015	32.6 ± 0.86 b	37.3 ± 1.49 a
Excell	3.7 ± 0.34 a	2.5 ± 0.09 b	–31	219 ± 22 a	165 ± 4 b	0.061 ± 0.0015	0.066 ± 0.0011	28.0 ± 1.53	32.3 ± 1.29
Red Coach 74	3.5 ± 0.28 a	2.4 ± 0.26 b	–32	201 ± 19 a	160 ± 16 b	0.061 ± 0.0032	0.068 ± 0.009	31.5 ± 1.05	32.2 ± 1.61
Batavia Doree De Printemps	2.3 ± 0.24 a	1.6 ± 0.13 b	–33	136 ± 14	118 ± 10	0.058 ± 0.0003 b	0.075 ± 0.0007 a	15.1 ± 0.37 b	19.3 ± 1.63 a
Wintercut	2.8 ± 0.22 a	1.9 ± 0.13 b	–34	169 ± 19	133 ± 25	0.061 ± 0.0014 b	0.070 ± 0.0015 a	30.8 ± 1.26	33.3 ± 1.50
Laupili	4.3 ± 0.38 a	2.8 ± 0.28 b	–34	250 ± 23 a	179 ± 21 b	0.061 ± 0.0009	0.063 ± 0.0019	26.7 ± 1.42	29.2 ± 1.06
Valverde	3.3 ± 0.25 a	2.1 ± 0.12 b	–36	194 ± 16 a	143 ± 8 b	0.059 ± 0.0006 b	0.067 ± 0.0006 a	28.6 ± 0.48 b	31.2 ± 0.83 a
Tiber	4.3 ± 0.47 a	2.7 ± 0.25 b	–37	256 ± 27	208 ± 15	0.064 ± 0.0012 b	0.072 ± 0.0015 a	35.7 ± 1.30	36.4 ± 1.79
Nagan 18	2.7 ± 0.28 a	1.7 ± 0.19 b	–39	183 ± 14 a	138 ± 15 b	0.068 ± 0.0012 b	0.083 ± 0.0013 a	30.9 ± 1.15	34.2 ± 0.98
Sumi	1.4 ± 0.16 a	0.8 ± 0.10 b	–40	86 ± 19	55 ± 10	0.067 ± 0.0012	0.066 ± 0.0016	29.6 ± 1.21	31.6 ± 1.41
Red Coach	4.8 ± 0.26 a	2.9 ± 0.27 b	–40	287 ± 16 a	189 ± 17 b	0.059 ± 0.0003 b	0.066 ± 0.0004 a	33.4 ± 1.47	38.6 ± 2.40
Empire 2000	2.5 ± 0.24 a	1.5 ± 0.25 b	–40	147 ± 14 a	99 ± 16 b	0.060 ± 0.0009 b	0.067 ± 0.0014 a	27.8 ± 1.74	28.6 ± 2.53
Durango	2.7 ± 0.31 a	1.6 ± 0.11 b	–41	148 ± 22	116 ± 7	0.058 ± 0.0021 b	0.073 ± 0.0012 a	32.0 ± 0.41	35.1 ± 1.34
Syr 0783 "Winter Select"	3.1 ± 0.32 a	1.8 ± 0.29 b	–43	190 ± 19	131 ± 20	0.059 ± 0.0008 b	0.073 ± 0.0023 a	31.5 ± 0.99	34.7 ± 1.07
PI 342476	3.6 ± 0.48 a	2.0 ± 0.31 b	–44	227 ± 33	158 ± 25	0.064 ± 0.0012 b	0.079 ± 0.0026 a	29.81.59 b	34.5 ± 0.92 a
Great Lakes Premier	2.2 ± 0.22 a	1.2 ± 0.06 b	–45	127 ± 14 a	86 ± 5 b	0.061 ± 0.0008 b	0.072 ± 0.0022 a	28.5 ± 1.11 b	34.7 ± 0.65 a
Telluride	3.4 ± 0.30 a	1.9 ± 0.07 b	–45	205 ± 15 a	136 ± 8 b	0.066 ± 0.0008	0.072 ± 0.0037	32.7 ± 0.99	35.4 ± 1.34
Sniper	4.8 ± 0.28 a	2.5 ± 0.19 b	–49	276 ± 17 a	166 ± 13 b	0.061 ± 0.0008	0.067 ± 0.0028	35.0 ± 1.03	38.8 ± 1.83
Number 749 (Imperial)	4.2 ± 0.61 a	2.2 ± 0.21 b	–49	241 ± 38 a	147 ± 14 b	0.061 ± 0.0010 b	0.068 ± 0.0017 a	29.7 ± 2.09	35.1 ± 1.54
Early Bird	3.3 ± 0.24 a	1.6 ± 0.17 b	–54	186 ± 14 a	108 ± 11 b	0.057 ± 0.0003 b	0.069 ± 0.0007 a	32.1 ± 1.17	31.4 ± 4.18
E 8248	3.2 ± 0.22 a	1.4 ± 0.20 b	–56	192 ± 12 a	89 ± 14 b	0.060 ± 0.0010	0.062 ± 0.0020	33.2 ± 1.12	38.1 ± 2.77

[z]Means of two trial followed with standard error (n = 6).

[y]Means followed by different letters within each genotype for each parameter indicate significant difference at $P \leq 0.05$ according to Student's t test.

reduction in FW of salt stressed plants, respectively. Cultivar Bursc 17 was salt tolerant in terms of both absolute and relative growth.

Romaine lettuce. Without salt stress, the highest FMs were found in cultivars Heart's Delight (5.3 g), Green Forest (5.2 g), Rome 59 (5.1 g), Parris Island (5.0 g), and D.F. 47 (4.7 g) (Table 3). Under salinity stress, shoot FM ranged from 1.0 to 3.2 g (Table 3). The five most tolerant genotypes were 'Green Forest' (3.2 g), 'Heart's Delight' (2.7 g), PI 289021 (2.7 g), 'Parris Island' (2.5 g), and 'Rome 59' (2.5 g), while the most sensitive ones were PI 177425 (1.0 g), PI 278070 (1.0 g), and 'Dark Green Romaine' (1.1 g). Parris Island was also rated as a salt-tolerant cultivar based on absolute growth by Shannon and McCreight (1984). Cultivars Heart's Delight, Green Forest, Rome 59, and Parris Island might be good choices for lettuce growers since they had highest growth regardless of salinity.

Eight genotypes ('Dark Green Romaine', 'Eruption', PI 289023, PI 273577, PI 278066, PI 177425, PI 176585, and PI 358017) did not show significant FM reduction under salinity. Based on relative tolerance, seven genotypes ('Dark Green Romaine', 'Eruption', PI 289023, PI 273577, PI 278066, PI 177425, and PI 176585) had high tolerance with less than 20% reduction, and four (PI 358017, PI 174228, PI 278082a, and PI 278070) had moderate tolerance with less than 30% reduction in FM. 'Rome 59', 'Romana Larga Blanca', and PI 120962c were the most sensitive genotypes.

Leaf lettuce. The cultivars that showed high growth under control conditions were Big Red (5.5 g), Two Star (5.3 g), Shining Star (5.2 g), Red Fox (5.0 g), and Prizehead (4.7 g) (Table 4). Shoot FM under salinity stress ranged from 0.4 to 2.9 g. The five genotypes with highest absolute growth under salinity were 'Big Red' (2.9 g), 'Red Fox' (2.9 g), 'Two Star' (2.8 g), 'Prizehead' (2.5 g), and PI 171676a (2.5 g). The cultivars with best growth under both control and salt stress were Big Red, Red Fox, Two Star, and Prizehead. Shannon et al. (1983) rated Prizehead as salt sensitive, which was inconsistent with the present results, and reported that Waldmann's Green had similar absolute growth under salinity to a benchmark cultivar Butter Crunch, which was consistent with the present result. In a later trial, however, Shannon and McCreight (1984) found that 'Prizehead' also had similar shoot fresh weight to 'Butter Crunch'. The five most sensitive genotypes were 'Greengo' (0.4 g), 'Sentry' (1.1 g), PI 175737 (1.2 g), PI 171675 (1.2 g), and PI 212099 (1.2 g).

Ten genotypes (PI 171676a, PI 177423, PI 342477, PI 358018b, PI 342452b, PI 175737, 'Sentry', 'Butter Beauty', 'Cabernet Red', and 'Nevada') did not show significant reductions in shoot FM under salinity stress. Six genotypes (PI 171676a, PI 177423, PI 342477, PI 358018b, 'Sentry', and 'Butter Beauty') showed less than 20% reduction in shoot FM under salinity, and 10 genotypes (PI 342452b, PI 175737, 'Cabernet Red', 'Nevada', 'Simpson', PI 171666a, PI 171675, 'Red Embers', PI 174225, and 'Waldmann's Green') showed less than 30% reduction. 'Greengo' and 'Shining Star' were the most sensitive genotypes with 62% and 57% FW reduction, respectively.

Wild lettuce. Four genotypes of primitive type had high shoot FM under both control and salt stress. They were PI 273579 (3.9 vs. 2.0 g for control and salt stress, respectively), PI 187238c (3.9 vs. 2.1 g), PI 250020 (3.7 vs. 2.1 g), and PI 491013 (3.2 vs. 2.0 g) (Table 5). Three *L. serriola* accessions, PI 491108a (0.5 g), PI 491173 (0.5 g), and PI 491154 (0.7 g), and the primitive PI 202349 (0.7 g), were the most sensitive ones to salinity stress. The primitive type of lettuce is believed to be evolved from *L. serriola* (Mou, 2008). Mutations in *L. serriola* and subsequent natural and artificial selections probably led to primitive forms of lettuce with higher biomass and/or salinity tolerance. Shannon and Grieve (1999) found that several wild relatives of cultivated lettuce, *L. serriola*, *L. vignata*, and *L. saligna*, had a wider range

Table 3. Effects of salinity on fresh and dry mass and chlorophyll index in romaine lettuce.

	Fresh mass (FM, g)			Dry mass (DM, mg)		DM/FM		SPAD	
Genotypes	Control	Salt	%	Control	Salt	Control	Salt	Control	Salt
PI 289023	1.7 ± 0.27[z]	1.7 ± 0.09	–2	140 ± 16	168 ± 21	0.074 ± 0.0058	0.099 ± 0.0097	18.0 ± 1.95	20.4 ± 2.10
PI 273577	1.5 ± 0.20	1.4 ± 0.18	–3	108 ± 14	109 ± 14	0.070 ± 0.0006 b	0.077 ± 0.0010 a	24.0 ± 2.33	29.8 ± 1.23
PI 278066	2.1 ± 0.31	1.9 ± 0.12	–7	136 ± 24	136 ± 10	0.067 ± 0.0032	0.071 ± 0.0008	21.6 ± 0.70 b	25.3 ± 0.90 a
PI 177425	1.1 ± 0.13	1.0 ± 0.09	–11	86 ± 10	81 ± 8	0.074 ± 0.0030	0.080 ± 0.0012	31.1 ± 1.29 b	37.4 ± 0.68 a
Dark Green Romaine	1.3 ± 0.10	1.1 ± 0.25	–16	85 ± 7	75 ± 16	0.064 ± 0.0012	0.067 ± 0.0015	20.7 ± 0.48 b	25.2 ± 1.33 a
PI 176585	2.4 ± 0.19	2.0 ± 0.25	–18	152 ± 10	147 ± 14	0.066 ± 0.0018 b	0.077 ± 0.0035 a	28.4 ± 1.17	29.8 ± 1.44
Eruption	1.9 ± 0.20	1.5 ± 0.21	–19	131 ± 14	115 ± 15	0.067 ± 0.0009 b	0.075 ± 0.0018 a	22.1 ± 0.64 b	26.3 ± 1.34 a
PI 358017	3.0 ± 0.19	2.4 ± 0.25	–22	184 ± 14	164 ± 18	0.063 ± 0.0010	0.069 ± 0.023	29.1 ± 0.88 b	32.7 ± 1.11 a
PI 174228	1.8 ± 0.18 a[y]	1.4 ± 0.17 b	–25	125 ± 12	98 ± 12	0.065 ± 0.0007 b	0.071 ± 0.0013 a	14.7 ± 0.43 b	17.2 ± 0.99 a
PI 278082a	3.0 ± 0.30 a	2.1 ± 0.13 b	–28	198 ± 21	158 ± 10	0.069 ± 0.0007	0.073 ± 0.0023	33.7 ± 0.81	32.6 ± 0.28
PI 278070	1.4 ± 0.13 a	1.0 ± 0.08 b	–29	106 ± 10	80 ± 7	0.072 ± 0.0006 b	0.078 ± 0.0025 a	32.7 ± 0.49 b	35.9 ± 0.55 a
PI 358040b	3.0 ± 0.42 a	2.1 ± 0.13 b	–32	198 ± 17 a	146 ± 15 b	0.068 ± 0.0012	0.070 ± 0.0034	24.2 ± 2.23	23.1 ± 0.85
PI 289021	3.9 ± 0.20 a	2.7 ± 0.23 b	–33	255 ± 16 a	166 ± 12 b	0.065 ± 0.0010	0.063 ± 0.0024	17.5 ± 1.39 b	23 ± 1.05 a
PI 278104a	2.7 ± 0.16 a	1.8 ± 0.11 b	–33	177 ± 11 a	129 ± 11 b	0.066 ± 0.0018	0.071 ± 0.0018	18.9 ± 0.72 b	22.8 ± 0.82 a
PI 278072	3.0 ± 0.34 a	1.9 ± 0.12 b	–35	175 ± 20	132 ± 8	0.060 ± 0.0002 b	0.068 ± 0.0010 a	26.0 ± 1.90	29.1 ± 2.29
PI 171672	2.7 ± 0.26 a	1.7 ± 0.19 b	–36	165 ± 17	127 ± 13	0.064 ± 0.0012 b	0.074 ± 0.0015 a	24.6 ± 1.62 b	31.8 ± 1.47 a
PI 169514b	2.6 ± 0.11 a	1.7 ± 0.23 b	–37	188 ± 9	151 ± 21	0.072 ± 0.0009 b	0.092 ± 0.0026 a	28.1 ± 1.09 b	31.4 ± 0.23 a
PI 174229	3.1 ± 0.32 a	1.9 ± 0.28 b	–37	198 ± 21 a	134 ± 19 b	0.060 ± 0.0008 b	0.069 ± 0.0009 a	23.0 ± 1.33	25.3 ± 1.36
PI 169510a	2.7 ± 0.07 a	1.6 ± 0.14 b	–39	193 ± 6 a	123 ± 10 b	0.072 ± 0.0016	0.076 ± 0.0007	33.2 ± 1.42	33.2 ± 0.66
PI 140395a	3.6 ± 0.22 a	2.2 ± 0.16 b	–39	209 ± 13 a	136 ± 9 b	0.056 ± 0.0023	0.062 ± 0.0006	24.2 ± 0.53	26.7 ± 1.25
Green Forest	5.2 ± 0.42 a	3.2 ± 0.22 b	–39	333 ± 29 a	235 ± 16 b	0.063 ± 0.0020 b	0.077 ± 0.0012 a	41.1 ± 1.73	42.3 ± 1.25
PI 183684	3.8 ± 0.24 a	2.3 ± 0.15 b	–40	217 ± 13 a	153 ± 10 b	0.055 ± 0.0003 b	0.068 ± 0.0006 a	19.4 ± 1.11	20.6 ± 1.53
PI 142872	3.7 ± 0.29 a	2.2 ± 0.21 b	–41	269 ± 20 a	160 ± 17 b	0.068 ± 0.0010	0.072 ± 0.0018	33.6 ± 0.53	36.3 ± 1.13
PI 289021a	3.5 ± 0.16 a	2.1 ± 0.10 b	–42	226 ± 12 a	146 ± 7 b	0.066 ± 0.0016	0.071 ± 0.0012	26.5 ± 1.30	28.5 ± 2.44
PI 140398	3.2 ± 0.44 a	1.8 ± 0.16 b	–44	202 ± 28 a	127 ± 9 b	0.063 ± 0.0006 b	0.071 ± 0.0020 a	30.4 ± 0.69	31.6 ± 4.15
Athena	3.2 ± 0.53 a	1.7 ± 0.17 b	–46	233 ± 38 a	124 ± 14 b	0.063 ± 0.0015 b	0.072 ± 0.0012 a	35.2 ± 0.91	36.5 ± 0.62
Catalana De Repollo Verde	3.2 ± 0.36 a	1.7 ± 0.13 b	–46	193 ± 23 a	114 ± 9 b	0.064 ± 0.0011	0.067 ± 0.0019	30.5 ± 1.33 b	35.9 ± 0.90 a
PI 140395	3.7 ± 0.23 a	1.9 ± 0.18 b	–47	234 ± 14 a	138 ± 12 b	0.063 ± 0.0013 b	0.072 ± 0.0010 a	31.6 ± 0.86 b	35.1 ± 0.85 a
D.F. no. 47	4.7 ± 0.21 a	2.4 ± 0.18 b	–48	283 ± 10 a	157 ± 12 b	0.060 ± 0.0010	0.064 ± 0.0015	36.3 ± 0.64	36.6 ± 1.11
PI 141680	3.4 ± 0.52 a	1.7 ± 0.20 b	–48	215 ± 15 a	133 ± 15 b	0.069 ± 0.0009 b	0.077 ± 0.0008 a	28.9 ± 0.68 b	31.8 ± 0.91 a
Heart's Delight	5.3 ± 0.88 a	2.7 ± 0.28 b	–49	280 ± 24 a	184 ± 18 b	0.060 ± 0.0027	0.067 ± 0.0007	33.8 ± 1.37	35.9 ± 1.50
Parris Island	5.0 ± 0.32 a	2.5 ± 0.33 b	–49	291 ± 14 a	176 ± 27 b	0.059 ± 0.0007 b	0.069 ± 0.0020 a	33.6 ± 1.41 b	41.6 ± 2.11 a
PI 120962c	4.3 ± 0.34 a	2.2 ± 0.24 b	–50	262 ± 20 a	148 ± 13 b	0.058 ± 0.0007 b	0.069 ± 0.0016 a	22.4 ± 0.92 b	27.2 ± 1.10 a
Rome 59	5.1 ± 0.42 a	2.5 ± 0.18 b	–52	347 ± 36 a	197 ± 18 b	0.061 ± 0.0009 b	0.077 ± 0.0018 a	33.4 ± 1.17 b	38.7 ± 1.93 a
Romana Larga Blanca	2.7 ± 0.13 a	1.3 ± 0.23 b	–52	160 ± 8 a	94 ± 16 b	0.060 ± 0.0002 b	0.073 ± 0.0009 a	20.3 ± 0.70 b	26.1 ± 1.40 a

[z]Means of two trial followed with standard error (n = 6).

[y]Means followed by different letters within each genotype for each parameter indicate significant difference at $P \leq 0.05$ according to Student's *t* test.

Table 4. Effects of salinity on fresh and dry mass and chlorophyll index in leaf lettuce.

	Fresh mass (FM, g)			Dry mass (DM, mg)		DM/FM		SPAD	
Genotypes	Control	Salt	%	Control	Salt	Control	Salt	Control	Salt
PI 171676a	2.7 ± 0.18[z]	2.5 ± 0.21	–5	175 ± 10	179 ± 14	0.067 ± 0.0018	0.071 ± 0.0009	26.8 ± 1.15	28.4 ± 1.35
PI 177423	2.2 ± 0.12	2.0 ± 0.17	–6	119 ± 6	131 ± 10	0.056 ± 0.0009 b	0.065 ± 0.0011 a	17.4 ± 0.95	17.6 ± 1.55
PI 342477	2.6 ± 0.29	2.4 ± 0.13	–10	153 ± 17	151 ± 10	0.059 ± 0.0003 b	0.064 ± 0.0024 a	11.5 ± 0.41 b	13.4 ± 0.41 a
PI 358018b	2.7 ± 0.41	2.4 ± 0.23	–12	182 ± 27	166 ± 10	0.066 ± 0.0025	0.070 ± 0.0034	20.9 ± 1.02	24.3 ± 1.17
Sentry	1.3 ± 0.10	1.1 ± 0.12	–18	86 ± 7	83 ± 9	0.061 ± 0.0006 b	0.075 ± 0.0011 a	20.6 ± 4.15	18.9 ± 1.61
Butter Beauty	2.8 ± 0.32	2.3 ± 0.38	–18	156 ± 18	141 ± 24	0.060 ± 0.0013	0.062 ± 0.0011	21.8 ± 1.37	22.8 ± 1.31
PI 342452b	2.7 ± 0.35	2.2 ± 0.21	–21	153 ± 19	144 ± 14	0.056 ± 0.0008 b	0.067 ± 0.0009 a	17.1 ± 0.84	18.4 ± 0.94
PI 175737	1.6 ± 0.20	1.2 ± 0.04	–22	90 ± 10	87 ± 4	0.053 ± 0.0006 b	0.070 ± 0.0012 a	18.8 ± 2.96	14.5 ± 0.49
Cabernet Red	2.4 ± 0.24	1.8 ± 0.19	–23	161 ± 15	139 ± 14	0.067 ± 0.0005 b	0.076 ± 0.0007 a	19.1 ± 0.61	21.5 ± 1.23
Nevada	2.2 ± 0.26	1.7 ± 0.17	–23	121 ± 14	104 ± 11	0.056 ± 0.0016 b	0.062 ± 0.0009 a	18.1 ± 1.03 b	21.9 ± 0.71 a
Simpson Elite	2.4 ± 0.26 a[y]	1.8 ± 0.13 b	–26	131 ± 16	112 ± 7	0.055 ± 0.0024 b	0.064 ± 0.0019 a	14.8 ± 1.75	11.3 ± 0.30
PI 171666a	3.1 ± 0.18 a	2.3 ± 0.15 b	–26	191 ± 16	152 ± 17	0.057 ± 0.0003 b	0.065 ± 0.0011 a	22.0 ± 0.84 b	25.2 ± 0.56 a
PI 171675	1.7 ± 0.20 a	1.2 ± 0.12 b	–27	106 ± 12	81 ± 9	0.058 ± 0.0017	0.065 ± 0.0027	13.0 ± 0.80	15.4 ± 0.77
Red Embers	3.2 ± 0.16 a	2.3 ± 0.08 b	–28	179 ± 9	158 ± 6	0.057 ± 0.0024 b	0.068 ± 0.0009 a	13.4 ± 0.69 b	15.7 ± 0.59 a
PI 174225	3.0 ± 0.16 a	2.1 ± 0.11 b	–29	196 ± 11 a	159 ± 8 b	0.068 ± 0.0016 b	0.075 ± 0.0011 a	17.3 ± 0.70	18.5 ± 0.49
Waldmann's Green	3.2 ± 0.21 a	2.2 ± 0.13 b	–29	232 ± 14 a	152 ± 9 b	0.073 ± 0.0009	0.069 ± 0.0018	21.2 ± 0.92	23.5 ± 0.81
PI 274371	1.9 ± 0.18 a	1.3 ± 0.05 b	–30	102 ± 10	85 ± 3	0.059 ± 0.0010 b	0.066 ± 0.0003 a	17.7 ± 0.53 b	19.7 ± 0.56 a
PI 370471	1.8 ± 0.19 a	1.3 ± 0.10 b	–30	118 ± 12	98 ± 8	0.067 ± 0.0016 b	0.077 ± 0.0006 a	12.8 ± 0.81 b	15.4 ± 0.41 a
PI 289016	2.7 ± 0.32 a	1.9 ± 0.11 b	–31	157 ± 18	125 ± 9	0.055 ± 0.0005 b	0.067 ± 0.0012 a	12.5 ± 0.59 b	17.6 ± 1.84 a
PI 278080	2.8 ± 0.24 a	1.9 ± 0.31 b	–31	163 ± 13	141 ± 21	0.057 ± 0.0010 b	0.075 ± 0.0023 a	12.5 ± 0.84	12.7 ± 0.79
PI 212099	1.7 ± 0.10 a	1.2 ± 0.17 b	–31	98 ± 18	77 ± 14	0.057 ± 0.0008 b	0.066 ± 0.0026 a	12.2 ± 0.64	14.6 ± 1.22
PI 253467	2.5 ± 0.18 a	1.7 ± 0.11 b	–33	184 ± 8 a	133 ± 9 b	0.074 ± 0.0028	0.079 ± 0.0002	26.4 ± 0.50	27.6 ± 1.02
PI 289020	2.0 ± 0.38 a	1.4 ± 0.15 b	–33	158 ± 9 a	110 ± 13 b	0.070 ± 0.0014 b	0.081 ± 0.0015 a	18.6 ± 1.07	20.0 ± 0.37
PI 178923	2.6 ± 0.34 a	1.6 ± 0.17 b	–39	140 ± 20	105 ± 11	0.054 ± 0.0008 b	0.067 ± 0.0007 a	21.7 ± 2.85	18.6 ± 1.18
Rossa Di Trento	2.6 ± 0.19 a	1.5 ± 0.20 b	–40	143 ± 13 a	101 ± 14 b	0.057 ± 0.0013 b	0.065 ± 0.0009 a	11.9 ± 0.52 b	13.9 ± 0.66 a
Lollo	2.5 ± 0.23 a	1.5 ± 0.19 b	–40	189 ± 21 a	126 ± 11 b	0.062 ± 0.0014 b	0.072 ± 0.0010 a	14.9 ± 1.06 b	18.7 ± 0.54 a
Red Fox	5.0 ± 0.53 a	2.9 ± 0.37 b	–43	356 ± 38 a	252 ± 20 b	0.060 ± 0.0006 b	0.072 ± 0.0039 a	17.5 ± 0.87 b	20.8 ± 0.96 a
PI 278106a	3.0 ± 0.23 a	1.7 ± 0.14 b	–45	173 ± 14 a	119 ± 10 b	0.061 ± 0.0009 b	0.072 ± 0.0013 a	15.7 ± 1.25	17.2 ± 1.28
Prizehead	4.7 ± 0.29 a	2.5 ± 0.22 b	–47	291 ± 22 a	196 ± 16 b	0.055 ± 0.0012 b	0.068 ± 0.0020 a	11.8 ± 0.99 b	15.8 ± 0.66 a
Two Star	5.3 ± 0.56 a	2.8 ± 0.33 b	–47	347 ± 41 a	226 ± 25 b	0.062 ± 0.0008 b	0.070 ± 0.0003 a	28.8 ± 0.78	31.0 ± 1.07
Big Red	5.5 ± 0.31 a	2.9 ± 0.40 b	–48	377 ± 38 a	225 ± 23 b	0.062 ± 0.0020 b	0.073 ± 0.0016 a	22.8 ± 1.13	24.8 ± 0.88
Shining Star	5.2 ± 0.64 a	2.3 ± 0.10 b	–57	417 ± 78 a	217 ± 28 b	0.061 ± 0.0009 b	0.076 ± 0.0021 a	24.2 ± 0.55	24.5 ± 1.31
Greengo	1.1 ± 0.16 a	0.4 ± 0.05 b	–62	71 ± 11 a	33 ± 4 b	0.070 ± 0.0008 b	0.083 ± 0.0016 a	21.0 ± 1.16	23.8 ± 1.54

[z]Means of two trial followed with standard error (n = 6).
[y]Means followed by different letters within each genotype for each parameter indicate significant difference at $P \leq 0.05$ according to Student's *t* test.

Table 5. Effects of salinity on fresh and dry mass and chlorophyll index in wild lettuce.

	Fresh mass (FM, g)			Dry mass (DM, mg)		DM/FM		SPAD	
Genotypes[z]	Control	Salt	%	Control	Salt	Control	Salt	Control	Salt
PI 253468[3]	2.1 ± 0.19[y]	1.7 ± 0.20	–18	162 ± 15	153 ± 35	0.073 ± 0.0005	0.088 ± 0.0144	32.2 ± 0.59	34.9 ± 1.35
PI 491108a[1]	0.6 ± 0.08	0.5 ± 0.06	–27	63 ± 9	52 ± 7	0.101 ± 0.0011 b	0.113 ± 0.0043 a	36.5 ± 0.70 b	39.5 ± 0.99 a
PI 202349[2]	1.0 ± 0.13	0.7 ± 0.08	–33	113 ± 14	78 ± 9	0.111 ± 0.0039	0.109 ± 0.0028	28.5 ± 1.65 b	32.0 ± 0.54 a
PI 491013[2]	3.2 ± 0.29 a[x]	2.0 ± 0.14 b	–37	224 ± 17 a	143 ± 9 b	0.068 ± 0.0011	0.071 ± 0.0012	29.0 ± 1.24	31.1 ± 1.54
PI 251247[2]	2.2 ± 0.21 a	1.3 ± 0.15 b	–39	151 ± 14	109 ± 13	0.070 ± 0.0012 b	0.082 ± 0.0008 a	27.0 ± 0.50	29.8 ± 2.27
PI 142871a[3]	1.7 ± 0.20 a	1.0 ± 0.17 b	–43	129 ± 15	92 ± 15	0.081 ± 0.0008 b	0.095 ± 0.0059 a	28.8 ± 1.32	29.5 ± 1.76
PI 289015c[3]	1.8 ± 0.13 a	1.0 ± 0.05 b	–44	127 ± 6 a	78 ± 3 b	0.069 ± 0.0013 b	0.077 ± 0.0016 a	22.9 ± 0.91 b	26.1 ± 0.70 a
PI 491173[1]	0.9 ± 0.11 a	0.5 ± 0.05 b	–44	71 ± 8 a	44 ± 6 b	0.076 ± 0.0017	0.086 ± 0.0048	25.4 ± 0.72 b	28.5 ± 0.77 a
PI 250020[2]	3.7 ± 0.27 a	2.1 ± 0.18 b	–44	264 ± 20 a	186 ± 15 b	0.074 ± 0.0032 b	0.090 ± 0.0009 a	25.0 ± 0.88 b	30.8 ± 1.29 a
PI 289015a[3]	2.0 ± 0.21 a	1.1 ± 0.10 b	–45	159 ± 17 a	81 ± 8 b	0.076 ± 0.0011	0.073 ± 0.0007	24.8 ± 0.93	26.1 ± 0.89
PI 251246[2]	3.2 ± 0.24 a	1.8 ± 0.19 b	–45	236 ± 22 a	151 ± 14 b	0.071 ± 0.0064	0.086 ± 0.0022	28.0 ± 1.09 b	31.2 ± 0.40 a
PI 273579[2]	3.9 ± 0.30 a	2.0 ± 0.16 b	–47	259 ± 21 a	173 ± 14 b	0.070 ± 0.0009 b	0.085 ± 0.0022 a	30.0 ± 1.34	30.8 ± 1.65
PI 289015b[3]	2.4 ± 0.21 a	1.2 ± 0.08 b	–48	194 ± 11 a	110 ± 7 b	0.079 ± 0.0026 b	0.089 ± 0.0009 a	23.8 ± 0.36 b	26.1 ± 0.89 a
PI 187238c[2]	3.9 ± 0.28 a	2.1 ± 0.20 b	–48	253 ± 20 a	148 ± 16 b	0.068 ± 0.0011	0.072 ± 0.0017	23.0 ± 0.79 b	26.7 ± 1.26 a
PI 491154[1]	1.3 ± 0.12 a	0.7 ± 0.04 b	–50	105 ± 10 a	61 ± 4 b	0.085 ± 0.0028 b	0.094 ± 0.0027 a	27.5 ± 0.79 b	30.9 ± 0.92 a

[z]Wild lettuce includes [1]*Lactuca serriola*, and [2]primitive and [3]transitional types of *Lactuca sativa*.
[y]Means of two trial followed with standard error (n = 6).
[x]Means followed by different letters within each genotype for each parameter indicate significant difference at $P \leq 0.05$ according to Student's *t* test.

of salt tolerance than cultivars and PIs of *L. sativa*.

The shoot FM of three genotypes (PI 253468, PI 491108a, and PI 202349) were not significantly reduced by salinity. Most genotypes showed large relative reductions in shoot FM under salinity, compared with shoot FM under control. PI 253468 (transitional type) and PI 491108a had the least percent reduction, 18% and 27%, respectively.

Overall, salinity decreased lettuce shoot FM and DM, increased DM/FM ratio, and chlorophyll index, and had no effects on photochemical efficiency. Great variation in salt tolerance exits among lettuce genotypes. Generally, genotypes with high growth potential were relatively salt sensitive based on the percentage of growth reduction, while those with relatively high salt tolerance commonly had low growth potential under control condition. These relatively tolerant genotypes might be valuable to breeders to find the critical genes for salt tolerance, while lettuce growers might be more interested in the genotypes with high growth potential under control condition or high absolute tolerance under salinity. The results in this study provide guidelines to select salt-tolerant lettuce genotypes for both breeders and growers. Selected genotypes based on this study will be evaluated in the field for salinity tolerance.

Literature Cited

Ayers, A.D., C.H. Wadleigh, and L. Bernstein. 1951. Salt tolerance of six varieties of lettuce. Proc. Amer. Soc. Hort. Sci. 57:237–242.

Barassi, C.A., G. Ayrault, C.M. Creus, R. Sueldo, and M.T. Sobrero. 2006. Seed inoculation with

Azospirillum mitigates NaCl effects on lettuce. Sci. Hort. 109:8–14.
Dewey, D.R. 1962. Breeding crested wheatgrass for salt tolerance. Crop Sci. 2:403–407.
Eraslan, F., A. Inal, O. Savasturk, and A. Gunes. 2007. Changes in antioxidative system and membrane damage of lettuce in response to salinity and boron toxicity. Sci. Hort. 114:5–10.
Flowers, T.J., H.K. Galal, and L. Bromham. 2010. Evolution of halophytes: Multiple origins of salt tolerance in land plants. Func. Plant Biol. 37:604–612.
Hoagland, D.R. and D.I. Arnon. 1950. The water-culture method for growing plants without soil. Cali. Agri. Exp. Station Circ. 247.
Humphries, J.M. and F. Khachik. 2003. Distribution of lutein, zeaxanthin, and related geometrical isomers in fruit, vegetables, wheat, and pasta products. J. Agr. Food Chem. 51:1322–1327.
Kaya, C., D. Higgs, and E. Sakara. 2002. Response of two leafy vegetables grown at high salinity to supplementary potassium and phosphorus during different growth stages. J. Plant Nutr. 25:2663–2676.
Mohammadi, P. and A.H. Khoshgoftarmanesh. 2014. The effectiveness of synthetic zinc (Zn)-amino chelates in supplying Zn and alleviating salt-induced damages on hydroponically grown lettuce. Sci. Hort. 172:117–123.
Mota-Cadenas, C., C. Alcaraz-López, M.C. Martínez-Ballesta, and M. Carvajal. 2010. How salinity affects CO_2 fixation by horticultural crops. HortScience 45:1798–1803.
Mou, B. 2008. Lettuce, p. 75–116. In: J. Prohens and F. Nuez (eds.). Handbook of plant breeding, vegetables I, Asteraceae, Brassicaceae, Chenopodicaceae, and Cucurbitaceae. Springer, New York, NY.
Nicolle, C., N. Cardinault, E. Gueux, L. Jaffrelo, E. Rock, A. Mazur, P. Amouroux, and C. Rémésy. 2004. Health effect of vegetable-based diet: Lettuce consumption improves cholesterol metabolism and antioxidant status in the rat. Clin. Nutr. 23:605–614.
Orcutt, D.M. and E.T. Nilsen. 2000. The physiology of plants under stress: Soil and biotic factors, p. 177–236. Wiley, Hoboken, NJ.
Pérez-López, U., J. Miranda-Apodaca, A. Muñoz-Rueda, and A. Mena-Petite. 2013. Lettuce production and antioxidant capacity are differentially modified by salt stress and light intensity under ambient and elevated CO_2. J. Plant Physiol. 170:1517–1525.
Qadir, M., A. Tubeileh, J. Akhtar, A. Larbi, P.S. Minhas, and M.A. Khan. 2008. Productivity enhancement of salt-affected environments through crop diversification. Land Degrad. Dev. 19:429–453.
Ruan, C.J., J.A.T. da Silva, S. Mopper, P. Qin, and S. Lutts. 2010. Halophyte improvement for a salinized world. Crit. Rev. Plant Sci. 29:329–359.
Shannon, M.C. 1980. Differences in salt tolerance within 'Empire' lettuce. J. Amer. Soc. Hort. Sci. 105:944–947.
Shannon, M.C. and C.M. Grieve. 1999. Tolerance of vegetable crops to salinity. Sci. Hort. 78:5–38.
Shannon, M.C. and J.D. McCreight. 1984. Salt tolerance of lettuce introductions. HortScience 15:673–675.
Shannon, M.C., J.D. McCreight, and J.H. Draper. 1983. Screening tests for salt tolerance in lettuce. J. Amer. Soc. Hort. Sci. 108:225–230.
Wei, Z., M.M. Julkowska, J.O. Laloë, Y. Hartman, G.J. de Boer, R.W. Michelmore, P.H. van Tienderen, C. Testerink, and M.E. Schranz. 2014. A mixed-model QTL analysis for salt tolerance in seedlings of crop-wild hybrids of lettuce. Mol. Breeding 34:1389–1400.